Phase 1 - Reliable Wireless Data Acquisition and Control Techniques within Nuclear Hot Cell Facilities

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On this NEER project the University of Florida has investigated and applied advanced communications techniques to address data acquisition and control problems within the Fuel Conditioning Facility (FCF) at the Idaho National Engineering and Environmental Laboratory (INEEL) for Argonne National Laboratory-West (ANL-W). The goals of this project are to investigate and apply wireless communications techniques, including radio frequency and infrared techniques, to solve the problem of communicating with and controlling equipment and systems within a nuclear hot cell facility. Moreover, it is a project goal to achieve highly reliable systems and control to ensure safe nuclear operations. Achievement of these goals will allow the eventual elimination of through-the-wall hardwired cabling that is employed in the hot cell, along with all of the attendant problems that limit measurement mobility, flexibility, and reliability.

There have been several hurdles to accomplish in Phase 1 in order to achieve the project goals. These hurdles have been addressed in three Phase 1 tasks. The objectives and accomplishments of these tasks, with clarified statements of Phase 1 objectives, are described below.

1. **Objective:** Determine communications techniques that offer the best potential for penetrating the shielded walls used to construct nuclear hot cells and for alleviating the multipath signal effects encountered in this environment.
Accomplishments: Radio frequency (RF) and infrared wireless communications transceiver techniques have been evaluated in Phase 1 and both frequency regimes show viability for outside-to-inside hot cell and within hot cell communications. Several specific accomplishments have been achieved during Phase 1 through a collaborative effort with researchers at ANL-W. Functional hardware demonstrations using primarily 2.4 GHz RF wireless transceivers and associated data acquisition components have been performed at the University of Florida and at ANL-W. The RF wireless demonstrations have utilized commercial-off-the-shelf (COTS) components that have the potential to be constructed in radiation-tolerant designs. Methods for the realization of radiation-tolerant data acquisition component designs have been investigated as part of Task 2 and Task 3. Another important accomplishment has been a demonstration of RF signal penetration and data communications through the hot cell walls at ANL-W using wireless communications components at both 900 MHz and 2.4 GHz. More testing is required to establish the attenuation of the RF signal through the hot cell walls and the effects of multipath on the communications signal. The demonstration of RF signal penetration and data communications through the hot cell walls is a significant accomplishment that now allows more concentration to be placed on radiation-hardened component techniques and RF technology. Infrared data communications techniques have also been investigated as an alternative wireless transceiver technique. Several specially constructed infrared communications transceivers, capable of transmitting signals through the hot cell windows, have been tested. Infrared transceiver techniques may useful in combination with RF techniques to solve the hot cell wireless data acquisition problem to improve reliability and/or mitigate multipath signal effects.

2. **Objective:** Investigate robust data acquisition and control techniques that are able to operate in harsh radioactive environments.
Accomplishments: The wireless communications transceiver components and the data acquisition and interface components used in nuclear hot cell environments must be physically and environmentally robust in addition to radiation-tolerant. While many COTS components are adequate to handle the communications

protocols, data rates, and measurement functions required, they are designed with high levels of circuit integration and microprocessors. Many of the integrated circuits and microprocessors currently employed in these designs are not radiation-tolerant nor are they available in radiation-hardened equivalents. Several alternative techniques have been considered to deal with this aspect of the hot cell wireless communications problem. Task 2 has concentrated on design techniques which optimize the use of currently available radiation-hardened components, while Task 3 has concentrated on evaluating radiation effects and hardening a broader class of electronic components.

One technique to improve the radiation tolerance of the wireless data acquisition system is to simplify the design and provide only the level of functionality needed. For example, a data acquisition component may be designed to have limited capabilities such as read (data) only or write only, rather than full two-way data communications. This limited functionality will often suffice for the data acquisition and control needs within nuclear hot cells. Limited functionality translates into a simpler component design that may allow the elimination of high level integrated circuits (ICs) and microprocessors. After high level ICs have been eliminated or substantially reduced, a design can be realized with discrete components or other integrated circuits that can be obtained in radiation hardened versions. The University of Florida has collaborated with ANL-W researchers to determine the type of functionality needed for current and projected hot cell measurements. Fortunately, many near-term needs involve simple analog signal measurements, such as thermocouple measurements, that can be achieved with a simplified analog-to-digital converter and interface circuit design. During Phase 1 an analog-to-digital (A/D) converter has been built and tested using components that can be obtained in radiation-hardened versions. This A/D converter interfaces to a standard RS-232 digital communications interface and will perform many of the analog voltage measurement requirements in the FCF. During Phase 2 this design will be improved, constructed in a radiation hardened version and tested. It is expected that an A/D design with 300 Krad total dose capability will result.

A second technique that has been used to improve the overall radiation tolerance of the wireless data acquisition system has been to modularize functions. High and low radiation-tolerant circuits functions have been grouped in a way to maximize operational time of several modules and to minimize module replacements within the hot cell. An example is an RS-232 interface module designed for hot cell wireless data acquisition systems; this interface module is universally compatible with many wireless transceivers. During Phase 1 an RS-232 network module has been designed and tested that will handle all communications between standard data acquisition (DAQ) modules and wireless transceivers. Since the required components in the network module are discrete digital components, the design should be capable of operation to 1 MegaRad total dose when constructed with the radiation hardened components.

3 **Objective:** Investigate radiation-hardening techniques to mitigate the effects of radiation on data communications components.

Accomplishments: Understanding the effects of radiation on electronic components is an extremely important aspect of designing radiation-hardened systems. Certain electronic components and devices utilize technology that is more inherently immune to radiation effects, i.e. Gallium Arsenide, SOI, and SOS devices. Many system components utilize complementary metal-oxide semiconductor (CMOS) devices that are more susceptible to radiation. By characterizing failure mechanisms and failure rates, those devices that are more radiation sensitive can be either improved or possibly removed from a design. This task has concentrated on critical RF wireless system components to better understand where failures are occurring.

Early testing at ANL-W showed that a 900 MHz wireless RF transceiver failed within less than twenty-four hours of operation when inserted into the FCF. One of the failed components in the 900 MHz transceiver was identified as a micro-controller. Subsequently, a Motorola MC68HC11 micro-controller similar to the failed device in this transceiver was tested in the UF Cobalt Irradiation Facility. This IC is built with high-density CMOS technology. While monitoring functions on the micro-controller, a hard failure occurred at 12 KRad total dose. Micro-controllers have been identified as one radiation-sensitive component. The University of Florida has consulted with Motorola and pursuing steps to obtain radiation-hardened micro-controllers, microprocessors, and other devices from the Motorola Space Electronics group.

In an effort to identify other radiation-induced failures the University of Florida obtained several additional 2.4 GHz RF wireless transceivers for radiation testing and evaluation. Through a cooperative effort with the transceiver manufacturer, a test program and special test software are being developed to exercise and evaluate failure modes of the transceiver during irradiation. These tests will be completed during Phase 2. It is expected that significant insight will be obtained into specific device failures, failure mechanisms, and failure rates, through the effort.